Appendix 1. Using Tuna Vessel Observer Data to Estimate Trends in Dolphin Abundance: A Chronological Description (P. Perkins)

Introduction

In 1979, the Inter-American Tropical Tuna Commission (IATTC) began a program to develop statistical methods for estimating the abundance of dolphin stocks in the eastern tropical Pacific (ETP), using tuna vessel observer data (TVOD), in order "to obtain information on trends in population abundance in time" (Hammond and Laake 1983, pg. 565) and "in a way that allows trend estimates to be used for management purposes" (Buckland et al. 1992, pg. 1). From the beginning of the program[1], it was recognized that the data "include potential violations of the assumptions necessary for a random sample and for the use of line transect sampling techniques", and that the resulting "biases in the estimates ... dictate that the results [should be] investigated for trends over time and not taken as indicators of actual abundance" (Hammond and Laake 1983, pg. 565). However, it was also recognized that detection of population abundance trends is important in assessing impact of the tuna fishery on those stocks.

Because they represent the largest single source of ETP dolphin data, "the use of TVOD seems the natural choice for analyzing trends" (Anganuzzi 1993, pg. 183), and consequently the statistical methods and analyses of the data have evolved over time in an attempt to identify, quantify, and better account for potential biases, "to yield more robust estimates of population numbers and trends" (Buckland and Anganuzzi 1988, pg. 411). While recognizing that "these procedures are unlikely to remove all biases", a stated goal is that "analytic procedures should as far as possible be insensitive to those violations" (Buckland et al. 1992, pg. 1). The series of peer- reviewed papers listed in the Appendix document the modifications and additions, made over more than a decade of the program from 1983 to 1994, to a basic line transect analysis.

Biases that result from failures in statistical assumptions may be constant over time, or may change due to changes in fishing methods, data collection methods, environmental factors, or the dolphin population itself. Changing biases may be random from year to year, or may exhibit a temporal trend. Provided that "bias arising from the failure of an assumption [in the statistical model] is consistent across time" or "that bias shows no trend with time," the estimates may be used "solely as indices of relative abundance" (Buckland et al. 1992, pg. 2), i.e. the relative magnitude of any year-to-year changes in the estimates will reflect relative changes in actual abundance. On the other hand, because randomly fluctuating biases "will affect the performance of statistical tests designed to detect trends, and ultimately, our ability to draw

[1] e.g., Laake, J. L. 1981. Abundance estimation of dolphins in the eastern Pacific with line transect sampling -- a comparison of the techniques and suggestions for future research. Appendix 3 in Hammond, P.S. (ed.) Report of the workshop on tuna-dolphin interactions. *Inter-Amer. Trop. Tuna Commn. Spec. Rep. No. 4*, 259 pp.

conclusions about the status of populations," the methods designed and used by IATTC "were specifically aimed at reducing the magnitude of year-to-year fluctuations in the estimates due to changing biases" (Anganuzzi, 1993 pp. 183-184).

Where evidence suggests that certain biases have exhibited temporal trends (e.g., increased searching efficiency), the methods which were initially proposed have been "complemented with specific analyses" (Anganuzzi 1993, pg. 183) to account for the changes and to attempt to verify the robustness of the methods. Biases with a temporal trend component are of special concern, because their presence could invalidate conclusions drawn from a time series of abundance estimates.

The following sections briefly describe the evolution of the methods developed by scientists at the IATTC. Throughout that development, the goal has been to produce "relative estimates designed to monitor trends over time" (Anganuzzi et al. 1992, pg. 541) in abundance of specific ETP dolphin stocks. Thus, the description below pays particular attention to features that are designed to account for changing biases, as these are most relevant in assessing the validity of trend estimates.

## Abundance Estimation Methods

### Spatial Stratification

Spatial stratification has been used in the estimators from early on, but the specifics of the stratification schemes have changed as the spatial properties of the data have become better understood.

Most obviously, data must be stratified by geographic stock boundaries in order to obtain stock-specific estimates of abundance (Hammond and Laake 1983, pg. 572; Buckland and Anganuzzi 1988, pg. 412). The accepted stock boundaries, and in fact the stock definitions themselves, have changed over time, and the stratifications have changed to reflect this. The most recent analyses have included revised abundance estimates for the earliest years of available data, to take into account changes in stock definitions and boundaries since those data were collected (Anganuzzi and Buckland 1994, pg. 362).

More problematically, neither dolphin schools nor tuna vessel search effort are uniformly random within each stock range, a potential source of bias. In addition, fishing mode (i.e. log, school, and dolphin sets) affects the distribution of perpendicular distance data, and different modes predominate in different areas (Hammond and Laake 1983, pg. 575). Both features can lead to biased estimators; the latter can affect precision as well. Two solutions to these problems have been investigated.

Initially, data were stratified by both predominant fishing mode and by levels of search effort (Hammond and Laake 1983, pg. 572). Comparison with unstratified estimators indicated that this stratification scheme did in fact correct for the non- random search patterns (Hammond and Laake, 1983 pg. 587). However, it was found that stratifying by search effort led to high variances in the estimators of abundance. This was because the scheme created a “low-effort” stratum with a large area and poor sampling coverage (Buckland and Anganuzzi 1988, pg. 412).

A new post-stratification scheme, based on smoothed observed encounter rate, was implemented to avoid this problem, and comparison with the earlier scheme indicated that precision was improved (Buckland and Anganuzzi 1988, pg. 412). Subsequent modifications included stratification by smoothed observed mean sighting distance and smoothed observed mean school size (Anganuzzi and Buckland 1989, pg. 324). Together, these stratifications are intended to account for potential biases resulting from spatial correlations between search effort and the three components of the abundance estimates (encounter rate, effective strip width, and mean school size), by allowing estimates of the three components to be made over more homogeneous regions (Anganuzzi and Buckland 1989, pg. 323). A simulation study indicated that the post-stratification method does in fact reduce bias when sampling is highly correlated with density (Anganuzzi and Buckland 1993).

Stratification by year has been used consistently, except in cases where data must be pooled across years because of an insufficient number of sightings (Buckland and Anganuzzi 1988, pg. 417). Seasonal stratification, though never implemented, has been investigated. Evidence was found for only a small bias due to correlated seasonal patterns in dolphin density and search effort (Buckland and Anganuzzi 1988, pg. 418).

Variance Estimation

Estimates of variance for the abundance estimators are extremely important in analyzing trends in abundance, in that they quantify whether year-to-year differences in estimated abundances can be attributed to sampling variance rather than changes in actual abundance.

Initially, analytic approximations were used to estimate variances (Hammond and Laake 1983, pg. 566). However, when the more complex post-stratification scheme was implemented, it was recognized that the assumptions necessary for these approximations were violated, leading to underestimation of variances (Buckland and Anganuzzi 1988, pg. 417), both due to the details of the post-stratification scheme (Anganuzzi and Buckland 1993, pg. 829), and due to dependence between the three estimator components (Anganuzzi and Buckland 1989, pg. 324). Consequently, bootstrap estimators of variance were implemented, which do not depend on assumptions of independence between stratum definition and the data, and between the three components.

Later, it was recognized that variances were still being underestimated: year-to- year differences, while statistically significant with respect to the estimated variances, were biologically implausible (Buckland et al. 1992, pp. 7-8). This problem is associated with unaccounted variance due to fluctuating environmental conditions (Buckland et al. 1992, pg. 8). A smoothing algorithm (described below) has been implemented to address this problem, and precision is now reported in the form of Monte Carlo confidence bands from this algorithm (Buckland et al. 1992, pg. 4).

Changes in Sighting Efficiency

As new technologies and fishing methods are introduced to the fishery (helicopters, bird radar, dolphin-safe fishing), the encounter rate for dolphin schools can be expected to change. However, the effective strip width parameter, estimated using the line transect model, in theory accounts for some of these changes (Buckland et al. 1992, pg. 3), leading to stable relative abundance estimates. In practice, estimated effective strip widths have shown little dependence on the increasing use of helicopters over the early years of the program, possibly due to the use of an appropriate perpendicular truncation distance (Buckland and Anganuzzi 1988, pg. 415). Similarly, the increasing use of bird radar had little effect on estimates (Anganuzzi et al. 1991, pg. 505).

A decreased prevalence of dolphin fishing could lead to a significantly lowered detection probability on the track line, which is not accounted for by the strip width parameter. However, no evidence was found that abundance estimates were affected during time periods when dolphin fishing was low (Anganuzzi and Buckland 1989, pg. 334; Anganuzzi et al. 1993, pg. 464).

Data Smearing

Line transect analysis requires measurements of a sighting's perpendicular distance from the trackline. In practice, a range and bearing from the tuna vessel's position and heading at the time of sighting are taken. These are difficult to measure accurately, and in particular, observers tend to round bearings to convenient values (Hammond and Laake 1983, pg. 570). Along with an appropriate binning of perpendicular distances (Hammond and Laake 1983, pg. 570), a data smearing algorithm has been implemented to account for rounding errors, initially with fixed smearing parameters (Buckland and Anganuzzi 1988, pg. 570), and subsequently with smearing parameters estimated from the data (Anganuzzi and Buckland 1989, pg. 414).

The introduction of bird radar had the potential to increase the precision with which range and bearing measurements may be made for some dolphin schools. Because perpendicular distance estimates are so dependent on bearing measurements (Anganuzzi et al. 1991, pg. 504), this had the potential to affect estimates of the effective strip width in ways which could not be accounted for by the line transect model. However, estimates of smearing parameters indicated that while range measurement has become more accurate over time, there has been little change in bearing measurement accuracy since the earliest years of data collection (Anganuzzi et al. 1991, pg. 504).

School Size Estimation

A description of the methods used to estimate mean school size was not presented in the initial methods paper, but it is clear that the difference between observer and crew estimates was recognized (Hammond and Laake 1983, pg. 587).

More recently, a correction was implemented to calibrate crew school size estimates with respect to observer estimates, because many sightings are only seen by the crew (Buckland and Anganuzzi 1988, pg. 413). To control bias due to size-dependent probability of detection, mean school size was estimated based on sightings within a limited perpendicular distance range (Buckland and Anganuzzi 1988, pg. 413).

## Trend Analysis Methods

Detection of trends (or lack of trends) in abundance has consistently been the end product of the analyses presented by IATTC scientists in the peer-reviewed literature. The results have been presented both as direct comparisons between annual abundance estimates, and as estimates of the actual rates of change.

Initially, only the individual annual abundance estimates and their standard errors were reported, and trends were investigated “by eye” (Hammond and Laake 1983, pp. 579-586). Later analyses included multiple comparison tests among years, as well as comparisons between pooled estimates from “early” and “late” periods of time (Buckland and Anganuzzi 1988, pg. 419). Weighted local linear regression lines were also fit to 5-year windows as a way to make “running” estimates of rate of change in abundance (Buckland and Anganuzzi 1988, pg. 419).

More recently, a non-parametric smoothing algorithm has been applied to the time series of annual abundance estimates. The time series and the associated Monte Carlo confidence bands produced by this estimator were found to have better properties than the local linear fits. Specifically, the time series are both smooth and biologically plausible (Buckland et al. 1992, pg. 3). In addition, a simulation study indicated that tests based on the non-parametric confidence bands were better able to detect trends (Anganuzzi 1993).

One motivation for using a smoothing algorithm to generate abundance time series estimates is that fluctuating environmental conditions can lead to different biases in abundance estimates for different years (Buckland et al. 1992, pg. 8). Particularly unusual years lead to abundance estimates which are effectively outliers, and the smoothing algorithm reduces their influence on analysis of trends (Anganuzzi 1993, pg. 184). A simulation study indicated that when such fluctuations do not have a temporal trend, the smoothing algorithm produces valid trend data when a suitably long time series is used (Buckland et al. 1992, pp. 8-9).

## Literature Cited

Anganuzzi, A. A. 1993. A comparison of tests for detecting trends in abundance indices of dolphins. Fish. Bull. 91:183-194.

Anganuzzi, A. A. and S. T. Buckland. 1989. Reducing Bias in Trends in Dolphin Relative Abundance, Estimated from Tuna Vessel Data. Rep. Int. Whal. Commn. 39:323-334.

Anganuzzi, A. A. and S. T. Buckland. 1993. Post-Stratification as a Bias Reduction Technique. J. Wildl. Manage. 57:827-834.

Anganuzzi, A. A. and S. T. Buckland. 1994. Relative Abundance of Dolphins Associated With Tuna in the Eastern Tropical Pacific Ocean: Analysis of 1992 Data. Rep. Int. Whal. Commn. 44:361-366.

Anganuzzi, A. A., S. T. Buckland, and K. L. Cattanach. 1991. Relative Abundance of Dolphins Associated with Tuna in the Eastern Tropical Pacific, Estimated from Tuna Vessel Sightings Data for 1988 and 1989. Rep. Int. Whal. Commn. 41:497- 506.

Anganuzzi, A. A., S. T. Buckland, and K. L. Cattanach. 1993. Relative Abundance of Dolphins Associated with Tuna in the Eastern Pacific Ocean: Analysis of 1991 Data. Rep. Int. Whal. Commn. 43:459-465.

Anganuzzi, A. A., K. L. Cattanach, and S. T. Buckland. 1992. Relative Abundance of Dolphins Associated with Tunas in the Eastern Tropical Pacific in 1990 and Trends Since 1975, Estimated from Tuna Vessel Sightings Data. Rep. Int. Whal. Commn. 42:541-546.

Buckland, S. T. and A. A. Anganuzzi. 1988. Estimated Trends in Abundance of Dolphins Associated with Tuna in the Eastern Tropical Pacific. Rep. Int. Whal. Commn. 38:411-437.

Buckland, S. T., K. L. Cattanach, and A. A. Anganuzzi. 1992. Estimating trends in abundance of dolphins associated with tuna in the eastern tropical Pacific Ocean, using sightings collected on commercial tuna vessels. Fish. Bull. 90:1-12.

Hammond, P. S. and J. L. Laake. 1983. Trends in Estimates of Dolphins (Stenella spp. and Delphinus delphis) Involved in the Purse-Seine Fishery for Tunas in the Eastern Pacific Ocean, 1977-81. Rep. Int. Whal. Commn. 33:565-588.